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THE DEVELOPMENT OF THE CANADIAN MOBILE SERVICING SYSTEM KINEMATIC SIMULATION FACILITY

by:

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ABSTRACT

Canada will develop a Mobile Servicing System (MSS) as its contribution to the U.S./International Space Station Freedom. Components of the MSS will include a remote manipulator (SSRMS), a Special Purpose Dexterous Manipulator (SPDM), and a mobile base (MRS).

In order to support requirements analysis and the evaluation of operational concepts related to the use of the MSS a graphics based kinematic simulation/human-computer interface facility has been created.

The facility consists of the following elements:

(a) A two-dimensional graphics editor allowing the rapid development of virtual control stations.

(b) Kinematic simulations of the space station remote manipulators (SSRMS and SPDM), and mobile base.

(c) A three-dimensional graphics model of the space station, MSS, orbiter, and payloads.

These software elements combined with state of the art computer graphics hardware provide the capability to prototype MSS workstations, evaluate MSS operational capabilities, and investigate the human-computer interface in an interactive simulation environment.

This paper describes the graphics technology involved in the development and use of this facility.

1.0 INTRODUCTION

The Mobile Servicing System (MSS) will be Canada's contribution to the U.S./International space station. The MSS will play an important role in performing the following functions on the space station:

- Space station construction and assembly
- Transportation (External on the space station)
- Payload Handling (Deployment, retrieval, and berthing including the orbiter)
- Attached payload servicing (in the extravehicular environment)
- Space station maintenance (in the extravehicular environment)
- Crew extravehicular activity (EVA) support
- Space station safe haven support

1.1 MSS System Configuration

The space segment of the MSS comprises three elements; the MSC (Mobile Servicing Centre), the SPDM (Special Purpose Dextrous Manipulator), and the MMD (MSS Maintenance Depot).

The MSC comprises two sub-elements called the MRS (Mobile Remote Servicer) and the MT (Mobile Transporter). The MT is to be supplied by the United States and provides the MSC with translation, corner turning, and plane change capability. The MRS comprises a number of major systems. The MBS (MRS Base System) provides the structure which interfaces with the Mobile Transporter and accomodates payloads and the remaining systems of the MSC. The relocatable SSRMS (Space Station Remote Manipulator System) is provided as a system of the MSC.

Figure 1 illustrates some of the MSS equipment described above.

The intent of this paper is to describe the applications of graphics technology to the MSS systems design process and to the creation of the MSS Kinematic Simulation Facility.

The role of the facility within the overall systems design and space operations process will be described. Following this, technical details regarding the current uses, and hardware and software configuration of the facility will be discussed.

2.0 ROLE OF THE GRAPHICS WORKSTATION IN MSS SYSTEMS DESIGN AND OPERATIONS

The development of the MSS Kinematic Simulation Facility was driven by the need to rapidly prototype and evaluate candidate configurations and capabilities of manipulators and control stations in a cost-effective manner.

This facility forms an integral part of the systems design process providing input at all stages of the design. The following will describe the uses of the graphics workstation in relation to this process.

2.1 Derivation of Requirements

The ability to visualize abstract concepts allows a systems designer to gain insight into the system being designed. The knowledge gained thus allows the designer to define, refine, and verify system requirements in a more efficient manner.

The preliminary definition process consists of performing task analyses based on operational concepts and proposing designs or prototypes as implementation solutions to the requirements specified in the formal program requirements documentation.

Rapid prototyping capabilities allow the formulation and creation of many competing design concepts in a cost-effective manner.

All components of the MSS must operate within the environment imposed by the physical and logistical infrastructure of the space station. As a result, influences external to the MSS have a significant impact on the design process. A graphics workstation based simulation facility provides the capability to simulate these external influences and assess their impact on design solutions.

2.2 Pilot Evaluation

A prototype control station may be evaluated using such criteria as accuracy of control, user preference, response time, the ability to learn and re-learn to use the workstation, and the ability to transfer training between operators.[1] Pilot evaluation consists of allowing qualified personnel such as astronauts and human factors specialists to interact with the simulations and evaluate the various prototoypes in a realistic environment.

The results of the evaluations are quantified through the use of questionaires designed to elicit relevant comments and impressions from the reviewers.

2.3 Iteration

The iteration process consists of refining the design by integrating the best features of each prototype identified by the pilot evaluators into a new proposed design and re-submitting the design for evaluation.

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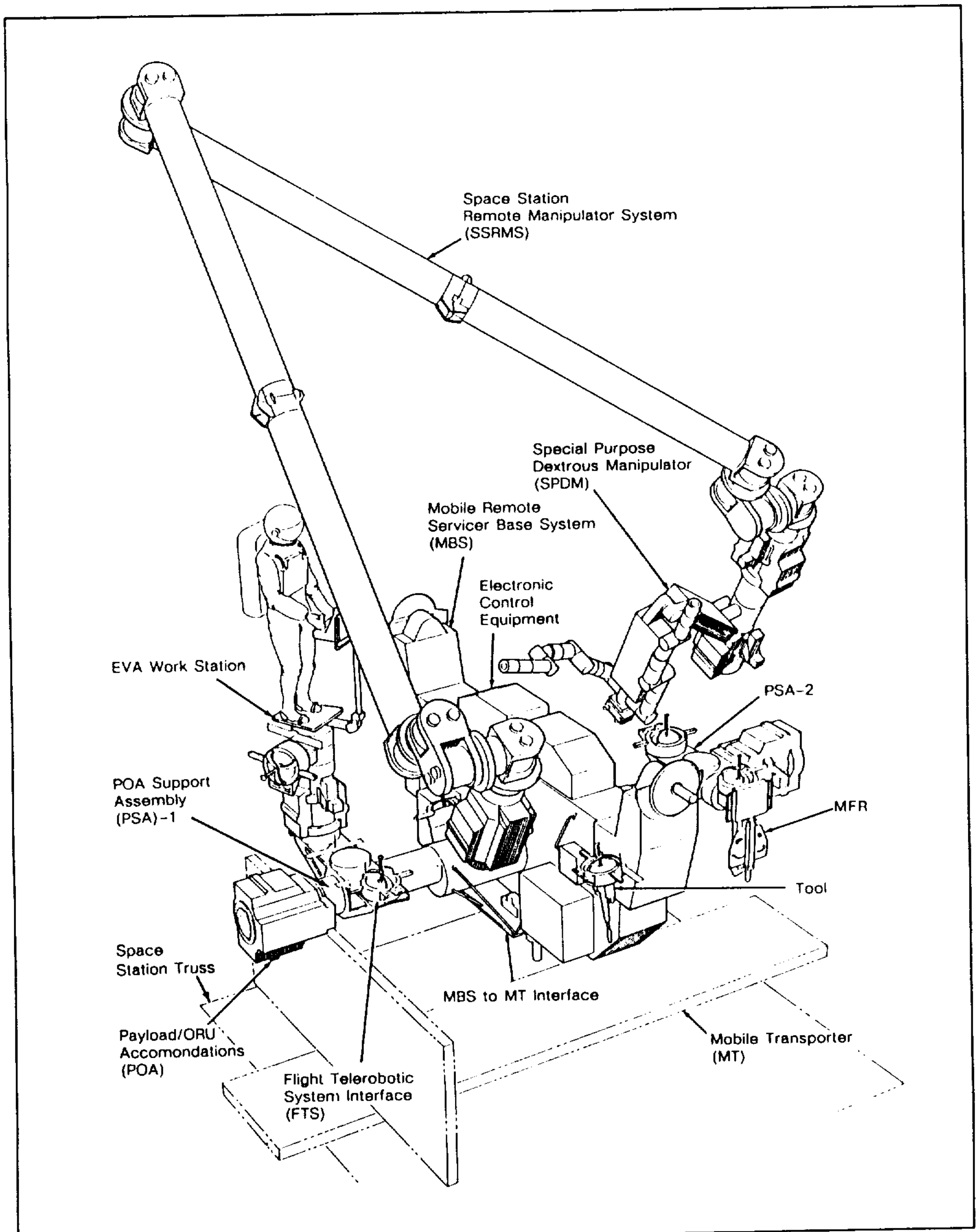

Figure 1 Mobile Servicing Centre (MSC)

2.4 Final Design

Eventually the prototypes will converge on a preferred configuration. The final design of the workstation may necessarily be a tradeoff between such factors as the capabilities of the available technology, requirements for interface commonality with other systems, operator preferences, and the impact of acceptable operational procedures.

3.0 MSS KINEMATIC SIMULATION FACILITY OVERVIEW

The intent of this section is to describe how the functional components of the facility are combined to provide an integrated simulation of MSS systems and how this capability is utilized in the development of the MSS.

3.1 Uses

The primary use for the MSS kinematic simulation facility is threefold:

- ❑ Operations Analysis

Operations analysis includes trajectory planning, reach analysis, viewing analysis, and evaluating the effectiveness/capability of the MSS to perform in the space station environment.

The outputs of operational analyses may effect the design of the MSS by providing critical information regarding the length of booms, and number, placement, and characteristics of joints. Information may also be obtained which impacts the space station design for operations using the MSS. In addition, viewing analyses assist in the preliminary definition of camera locations and quantities.

- ❑ Human-Computer Interface Development

Telerobotic applications rely on the ability of a human operator to directly control or supervise an operation. The definition, placement, size, colour, and functionality of the controls associated with the MSS will determine the ease with which the MSS will be operated. Evaluations of human-computer interface concepts are being performed in parallel with the systems design activities.

- ❑ Animated video production

Animated videos have been found to be an efficient method of conveying operational concepts and MSS capabilities. In addition, videos are excellent vehicles through which public awareness of space activities can be broadened.

3.2 Hardware Configuration

The MSS Kinematic Simulation Facility currently consists of a Silicon Graphics IRIS 4D 70-GT with 8 Mb of RAM, a 380 Mb hard drive, mouse, keyboard, 19 inch monitor with resolution of 1280 x 1024 pixels, 96 bitplanes, and an Ethernet card for communication with other hosts.

The operator's primary input devices are the keyboard, mouse, and a 6 degree of freedom handcontroller used for control of the manipulator. Other input devices such as a touch screen, trackball, discrete switches, and a voice recognition system may be added and evaluated serially or in parallel.

The hardware dedicated to the video recording function consists of an optical disk recorder, sync generator, IRIS genlock card, RGB Encoder, VHS editing video recorder, and an NTSC monitor.

Figure 2 depicts the current hardware configuration of the facility along with typical input/output device options.

3.3 Software Configuration

The facility operates in a Unix/C based stand-alone IRIS environment. Communication with other hosts for off-line processing is available however the stand-alone performance of the IRIS has been found to be sufficient for the current operational analyses and levels of simulation complexity. The iteration rate of the simulation varies between 3-5 Hz. depending on the number of simultaneous 3D windows being displayed and the processing demands of the kinematics.

Figure 3 depicts the current software configuration of the facility.

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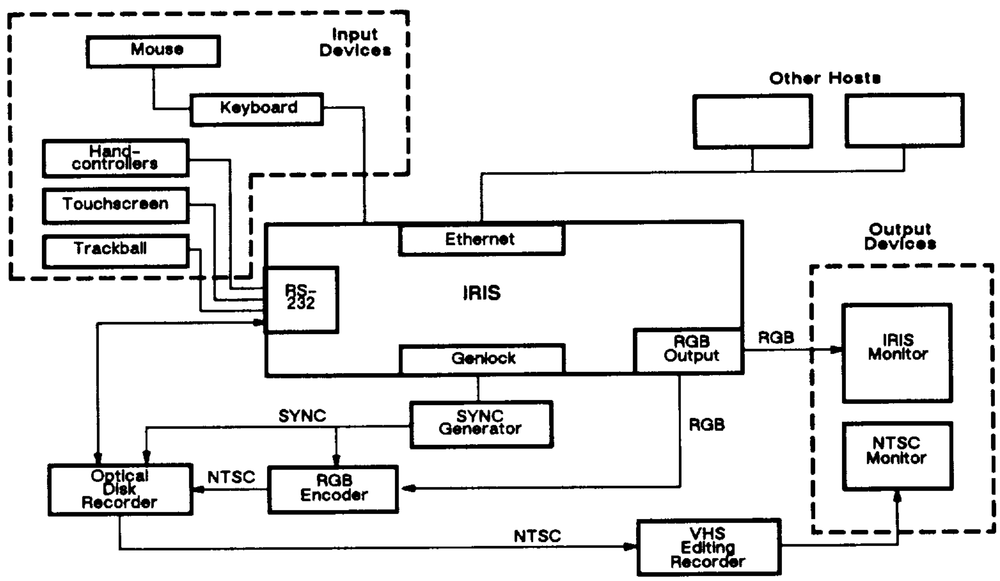


Figure 2 MSS Kinematic Simulation Facility Hardware Configuration

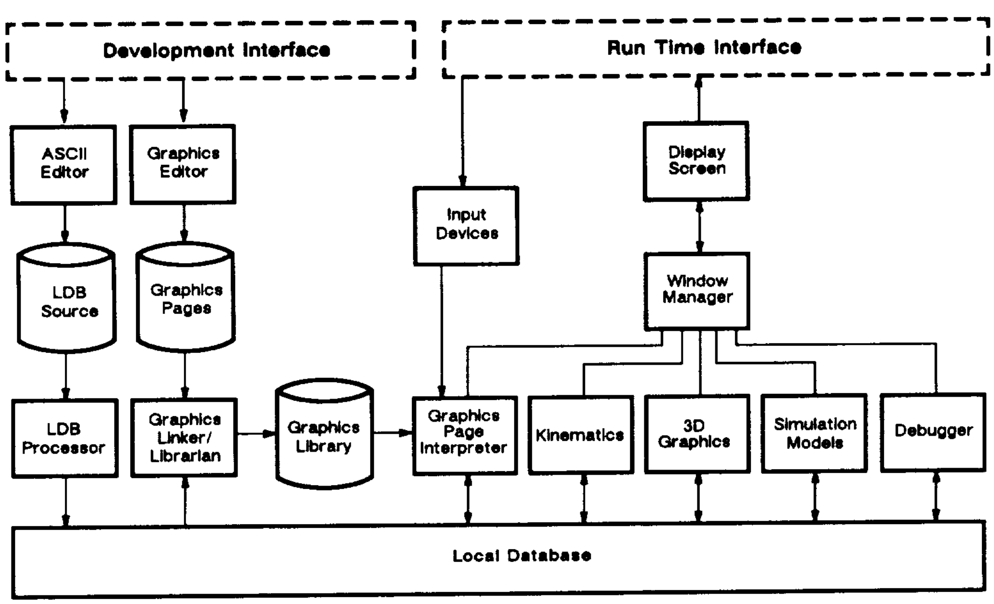


Figure 3 MSS Kinematic Simulation Facility Software Configuration

3.3.1 Simulation Environment

The MSS Kinematic Simulation Facility currently consists of the following simulation components:

- Two-dimensional virtual display and control panels
- Kinematic model of the space station remote manipulators
- Three-dimensional graphics animation of the space station, MSS, orbiter, and payloads
- Simulations of the operation of MSS systems.

TIGERS (The Integrated Graphics Environment for Real-Time Systems), a product of CAE Electronics, provides the simulation environment through which the MIKE (Manipulator Interactive Kinematics Evaluator) kinematic model and MIKEGRAF 3D animation software, produced by Spar Aerospace, are integrated with the 2D virtual display and control panels. Models of MSS systems are easily added to the simulation with all communication transpiring through a local database residing on the IRIS or a remote database residing on a remote host.

The simulation variables defined in the databases can also be displayed and controlled by the 2D virtual instruments created using the TIGERS graphics editor. The graphics editor pages are processed by a linker/librarian and then displayed by the graphics page interpreter as windows controlled by the TIGERS window manager. The 3D animations are also displayed as windows allowing the number of animation views, their size and location on the screen to be dynamically modified.

3.3.2 Two Dimensional Graphics Editor

Stylized panels and displays can be created using the on-screen graphical interface of the editor. Most inputs are made via pop-up menus and a standard 3-button mouse. The graphics editor provides a wide range of drawing tools, raster and vector fonts, and multiple dynamic attributes that can be applied to graphical elements of displays to make them respond to changing simulation variables. Examples of dynamic attributes include: color, size, position, rotation angle, and digital and alphanumeric readouts. Graphical elements can be combined into objects and stored in libraries for use on several display panels.

3.3.3 Virtual Displays and Controls

The virtual displays and controls created using the graphical editor provide the user interface for the MSS Kinematic Simulation Facility. The current interface consists of a parent screen, primary and secondary control areas, pulldown menus, and virtual control panels containing virtual instruments which interact with the MSS system simulations. Virtual instrumentation created using the editor includes digital readouts, icons, virtual pushbuttons, status indicators, and data input and feedback sliders. Figures 4 through 7 illustrate some typical prototype control panels developed for MSS applications.

3.3.4 System Simulations

Although some control over the attributes of the workstation prototype is available from the run-time services of the 2D graphical display manager, additional functionality may be achieved through the use of simulation routines which explicitly control the 2D graphical attributes. These routines would be required to simulate various menuing schemes or logic related to systems or subsystems driving the user interface.

3.3.5 Three Dimensional Graphic Modelling

Three dimensional (3D) graphical models of the environment may be created and rendered in individual windows under the control of the window manager. Typical objects used in operational analyses include the space station, orbiter, manipulators, payloads, and free flyers.

The 3D views are used to simulate out-of-window views from the orbiter or space station, views originating from various closed circuit television (CCTV) cameras, or synthetically generated images created from the space station master object database.

The graphical objects are created from combinations of the available 3D primitives which include boxes, cylinders, cones, spheres, and generic objects created by manipulation of

vertices and polygons. Attributes such as the position and orientation of a 3D object can be dynamically modified by generic simulation routines.

Objects may be individually rendered as wire frame, filled polygon, or Gouraud shaded polygons. From an operational analysis perspective, it has been found to be advantageous to allow concurrent display of wire frame and filled polygons as the former allows the operator a see-through capability which may assist in determining the relative position of objects. Object ordering is achieved through the use of the IRIS z-buffer which operates in double buffered mode.

The IRIS 4D-70 allows the use of multiple light sources to illuminate the workspace and allow some measure of realism to the view. It cannot however, adequately simulate the effects of shadowing and glare which have a significant effect on visibility in space.

Orthogonal or perspective viewpoints are available for display in each window. Viewing parameters including pan, tilt, roll and field of view, may be modified from a simulation routine which relies on inputs from the 2D virtual control domain or from alternate input devices such as hardware switches or buttons. In addition, the attachment location of a viewpoint (camera) may be tied to any object such as a manipulator which allows an assessment of viewing capabilities from manipulator cameras.

Graphical objects may be bound to other graphical objects to simulate the chaining of manipulators or the acquisition and maneuvering of payloads.

The 3D graphical displays are under the control of the window manager which provides the ability to:

- simulate graphics over video by the overlaying of 2D over 3D graphics.
- simulate split screen operation and resizing by manipulation of 3D windows using window manager services.

3.3.6 Kinematic Simulations

The configuration of the manipulator is controlled by a kinematic simulation routine which performs the inverse kinematics required to convert from a commanded point of resolution (POR) to the set of joint angles required to achieve the configuration. The set of joint angles along with the base position and orientation uniquely defines the manipulator configuration and may be used by the 3D graphical rendering routines to draw the manipulator.

The kinematic simulation currently implemented on the prototype has the following characteristics:

- "N" degrees of freedom: The SSRMS will consist of a 7 DOF manipulator.
- Bi-directional Control: The SSRMS will have the capability to attach itself to grapple fixtures which supply power and data transfer to both the base and end effectors. This feature means that the SSRMS can relocate itself by "walking" off of the MSC and operating from a grapple fixture at a remote location.
- Coordinate Re-referencing: The SSRMS may be controlled in any desired reference frame. Reference frames are selectable by the operator.
- Control Modes: Three main control modes are associated with the SSRMS kinematic model.

  Single Joint Mode: Manipulator joints may be controlled individually by the operator using a suitable input device.

  Automatic Mode: The manipulator configuration may be controlled by an automatic trajectory planner thus allowing the execution of pre-planned trajectories.

  Manual Augmented Mode: The manipulator POR may be controlled by a human operator using a handcontroller.

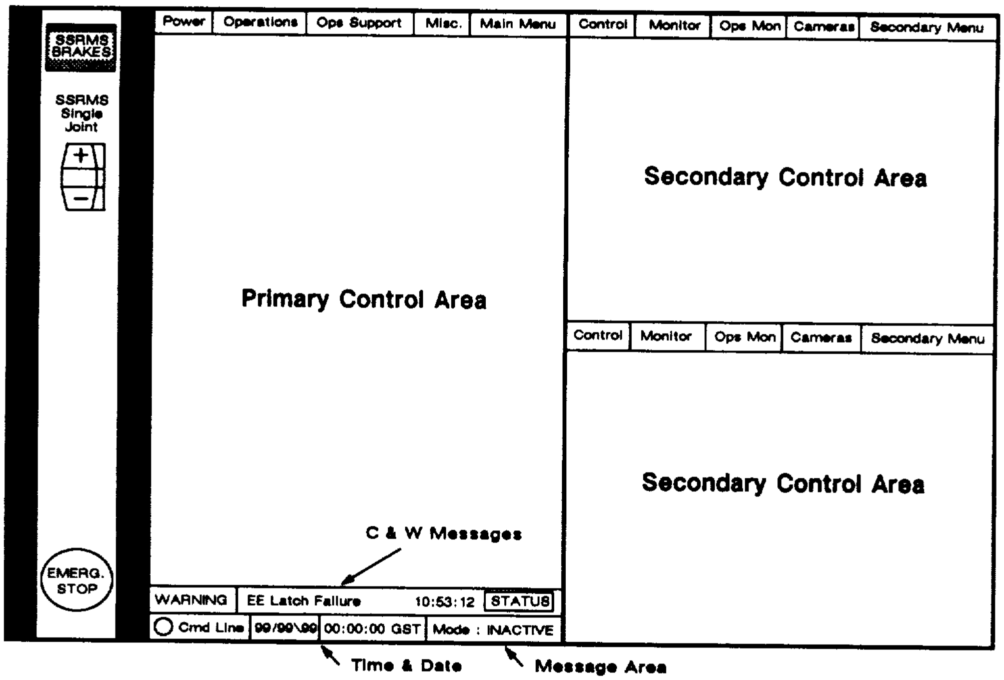
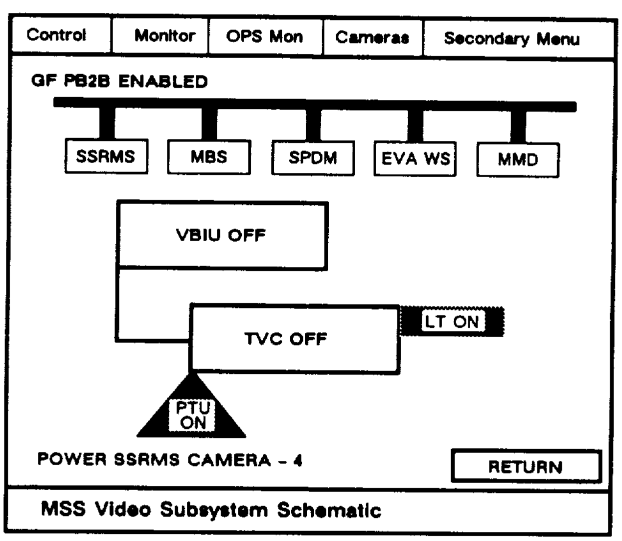


Figure 4 Graphical Display Template



NOTE: Figure is representative of the information required for display, not the implementation of how function will be displayed.

Figure 5 MSS Camera Power Control Panel Selection

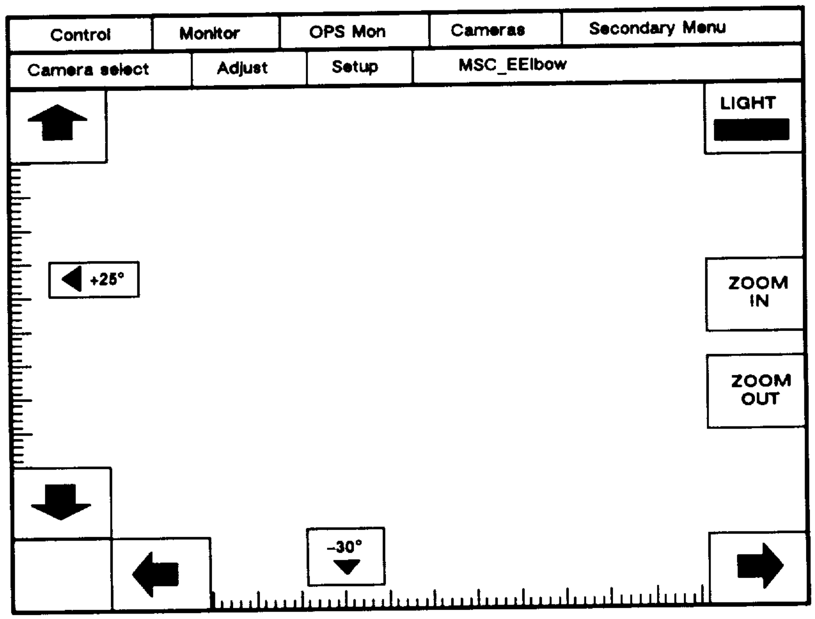


Figure 6 MSS Camera Control Panel

NOTE: Figure is representative of the information required for display, not the implementation of how function will be displayed.

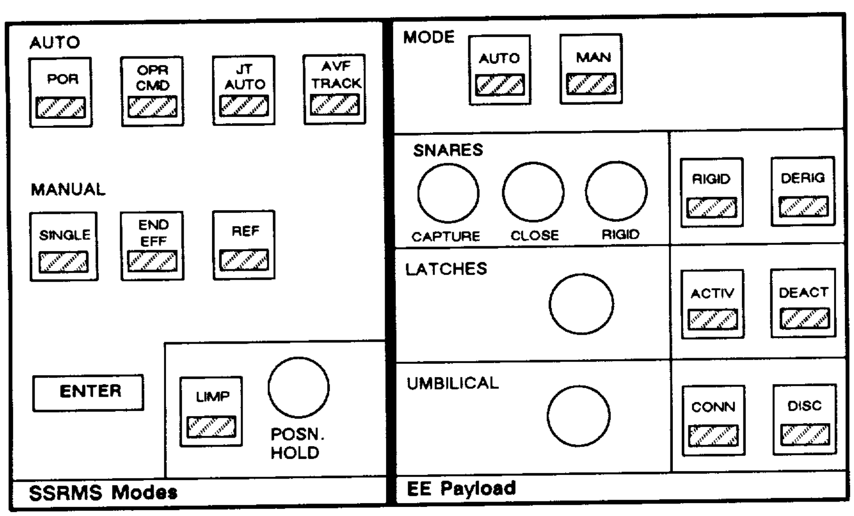


Figure 7 Manual End Effector Control - SSRMS Mode and Payload End Effector Panels

3.3.7 Post Processing Functions

Post processing software is included in the facility which allows analysis of simulation runs. Current post processing capabilities include workspace analysis and video recording and playback.

An interactive workspace analysis program allows multiple instances of manipulator positions to be superimposed. The investigator may then visually determine the point of closest approach between the manipulator and another object. The line of closest approach may be quantified by calculating the distance between the two points as defined with a 3D cursor.

After the definition of a manipulator trajectory the set of parameters relevant to the operation may be saved to disk for off-line trajectory post processing analyses or the creation of videos.

Animated videos may be created for engineering presentations or public relations. The video software will read the disk file, redraw the image, and sent the appropriate commands to the optical disk recorder for recording of the video image. The images thus stored are spliced together on a VHS editing tape recorder for production of the final video.

4.0 FUTURE DEVELOPMENTS

The MSS Program will achieve a higher level of simulation capability with the development and delivery of the MDSF (Manipulator Development and Simulation Facility). The MDSF will provide all the functionality of the MSS Kinematic Simulation Facility along with the following additional features:

- ❑ Real-time dynamic simulation of generic manipulators with multiple operator control stations
- ❑ 3D graphics editor
- ❑ Generic instructor station for operator training
- ❑ Record and Playback functions
- ❑ Simulation of elastic deformation of bodies
- ❑ Collision detection algorithms

5.0 CONCLUSION

An implementation of computer graphics technology in the design of a complex system has been presented, specifically related to the development of the Canadian Mobile Servicing System and its IVA human-computer interface. The systems design methodology, hardware and software configuration, and current and future uses of the facility have been discussed.

The application of currently available graphics technology provides systems designers and operations analysts with the ability to visualize and simulate the capabilities of a complex system in a cost-effective manner. The integration of input/output devices with the simulation facility provides a high degree of interactiveness allowing the testing and verification of concepts throughout the design process in a realistic environment.

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REFERENCES

[1] "Space Station Information System (SSIS) Human-Computer Interface Guide," Version 2.0, NASA USE-1000, May 1988